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# Investigation of temperature and its indices under climate change scenarios over different regions of Rajasthan state in India

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ABSTRACT

The ongoing increases in concentrations of atmospheric greenhouse gas will most likely affect global climate for the rest of this century. Global warming brings a huge provocation to society and human beings. Single extreme events and increased climate variability have a greater impact than long-term changes in the mean of climatic variables. This study analyzed the temperature projections for Rajasthan state, India using data obtain from two General Circulation Models (GFCM21 and HadCM3) for three Intergovernmental Panel on Climate Change (IPCC) Special Range of Emission Scenarios (SRES) A1B, A2, and B1. A 30 years of maximum (Tmax) and minimum (Tmin) temperature for the period 1976–2005 has been obtained from India Meteorological Department (IMD) and by using LARS-WG5 to generate the long-term weather series for three different periods i.e. 2011–2040 (2025s), 2041–2070 (2055s), and 2071–2100 (2085s). Further to determine the changes in extreme temperature events, the data for the baseline period and the future periods was represented by eight extreme temperature indices. Results illustrate that an increase in minimum and the maximum temperature are observed in all the three future periods. The average mean temperature for base period and three future periods over four regions of Rajasthan was observed highest in region 3 which shows an incessantly increased in mean temperature about 2.6 °C i.e. north-east and north-west part of Rajasthan. Two GCMs depicts that the incessant temperatures may be increase in the future and future maximum temperature in all the seasons varies from 2.43 °C to 4.27 °C in the direction from south to north of Rajasthan during 2071–2100. While for minimum temperature, the range of temperature changes varies from 0.23 °C to 1.42 °C from south-east to north-west of Rajasthan during 2011–2040. In the temperature indices, the number of tropical nights (TR20), warmest day (TX90p), warmest night (TN90p) and summer days (SU25) is expected to increase during all three future periods. The maximum changes was found in region 2 (39.4 days) and region 1 (38.8 days) during the 2071–2100 periods, followed by 2041–2070 and 2011–2040. In all the four regions, the annual occurrence of Cold Spells Duration Indicator (CSDI) decreased and Warm Spells Duration Indicator (WSDI) increased for all three future periods.

## 1. Introduction

Today, we are in the era of development, where the rapid population growth and increasing migration is unpredictable for urbanization of society. We are aware of various environmental issues and also take significant measures to mitigate them. In the context of temperature inconsistency, climate change is measured to be the greatest challenge faced by people in the 21st century (Intergovernmental Panel on Climate Change (IPCC), 2014). For the planning and management of future water resources in the respective areas, it is necessary to evaluate and forecast the change in climatic variables like temperature, which will provide a valuable reference (Sivakumar, 2011). In particular, there is increasing awareness about the frequency and intensity of extreme events that happen as a result of climate change (Solomon et al., 2007). Being such a large country, India shows a wide diversity of temperatures from scorching heat of the Thar Desert to the freezing cold winters in the Himalayas. The climate of India is dominated by the monsoon season which is the most important season of India, with annual rainfall of 80%. This season cover June to September with an average annual rainfall between 750 and 1500 mm across the region (Shukla, 2003).

The global average surface temperature has been increased over the twentieth century by about 0.6 °C, and the warming of the recent 50 years is largely attributed to human activities (Edenhofer et al.,

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2014; IPCC, 2014). India is among the highly affected countries where alteration of rainfall patterns and temperature has been noticed (IPCC, 2014; Jain and Kumar, 2012; Jain et al., 2013; Kundu et al., 2015; Tiwari et al., 2016). In a comparison to long-term changes in the mean of climatic variables, single extreme events, and increased climate contradiction are believed to have a greater impact (Fischer and Schär, 2009; Schär et al., 2004). Pattnayak et al. (2016) studied the relationship between rainfall and Tropospheric Temperature (TT) over the Indian subcontinent during four seasons of the year using Regional Climate Model Version 3.0 (RegCM3). Often, evaluation of climate change is implemented in two ways. The first way is trend analysis which is based on long time series of historic climate data performed by parametric and non-parametric test to analyze the climate change (Suryavanshi et al., 2014). It is important to know that trend analysis of a time series consists of the magnitude of trend and its statistical significance (Jain and Kumar, 2012). The second way for climate change analysis is Global Climate Models (GCMs) which helps through projecting future climate change under different emission scenarios based on GCMs (Semenov, 2009). Global Climate Models (GCMs) and Representative Concentration Pathway (RCPs) is the primary tools to use and predict the future change (Meehl et al., 2007; Frieler et al., 2011), but the information they provide remains relatively coarse in resolution (Chiew et al., 2010; Kumar et al., 2011). Pattnayak et al. (2013) presented that the regional climate model can simulates the Indian summer monsoon characteristics closely to the observations, mainly over the central northeast India, which includes Odisha. These GCMs used observed data to project future climate models in large scale and describe the causes and effects of climate change. GCMs have been widely used in various studies by many researchers to predict changes in climatic parameters (Hashmi et al., 2011). Pattnayak et al. (2017) successfully projected the climate for the 21st century using the fifth phase of Climate Model Inter-comparison Project (CMIP5) models under the Representative Concentration Pathways (RCPs) 4.5 and 8.5 over the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Co-operation (BIMSTEC) countries for the period 1901 to 2100 and analyzed that there are uncertainties within the CMIP5 model projections shows by inter-model comparison. As per the IPCC 4th assessment report (IPCC-AR4), continues increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (Kirtman et al., 2013) and indicates that the Earth could warm by 3 °C by 2100. Dash et al. (2012) simulated the temperature and precipitation fields over Northeast India (NEI) by using (RegCM3) under the IPCC A1B scenario for the period 1970–2100 and predicted some future changes. Climate changes have shown significant impacts on ecosystem functions and agricultural patterns from global to local scale (Sax and Gaines, 2003; Potts et al., 2010).

In rain-fed areas, a long-term climate data analysis plays an important role, particularly, temperature and precipitation, to develop future strategies for efficient water and crop planning (Kang et al., 2009). Reddy et al., 2012 explained that LARS-WG5 (Long Ashton Research Station Weather Generator) weather generator is well suited for semiarid regions as compare to other weather generator models. Semenov and Barrow developed a Long Ashton Research Station Weather Generator (LARS-WG5) which is a stochastic weather generator specially developed for climate change studies. The description of the latest version of LARS-WG5 and its capabilities is given in Semenov and Stratonovitch (2010). LARS-WG5 has an additional advantage: it incorporates climate projections from 15 GCMs for three SRES scenarios used in the IPCC-AR4. Sarkar et al. (2015) has applied the applicability of LARS-WG5 in the arid climate of Kutch, Gujarat and determined that LARS-WG5 is reasonably good to predict and downscaling of daily precipitation and temperature changes. To our knowledge, LARS-WG5 has not been applied for Rajasthan region before. Therefore, this study may also be viewed as an illustration of the application of LARS-WG5 in the Rajasthan region. Rajasthan has the maximum probability of occurrence of drought (Mall et al., 2006), and there have been 48 drought years of varied intensity observed in between the period of 1901–2002 (Rathore, 2004).

As it is predictable by many GCMs, in coming future, the frequency and magnitude of extreme events are increase under climate change (Chen et al., 2011; IPCC, 2014; Siliverstovs et al., 2010). The report of World Bank, 2014, stated that extreme events can cause loss of livestock and crop production and thus bring substantial risk to food security. The analyses of extreme events are imperative for impact assessment and for adaptation planning for the future (Dutta et al., 2015). The world is experiencing a high variability in climatic parameters stated by Singh and Kumar (2015). Heat waves and drought condition was increase due to changes in extreme weather events in the northern Indian region (Sen Roy and Singh, 2002). Single extreme events and increased climate contradiction are believed to have a greater impact than long-term changes in the mean of climatic variables (Fischer and Schär, 2009). Various studies show that Rajasthan is likely to suffer an additional water scarcity due to an overall decrease in rainfall. The arid region of the western part of India is under threat of severe droughts due to scantiness, irregularity of rainfall and severe climatic characteristics (Jain et al., 2013). Several studies have shown that Rajasthan state falls under the climate sensitivity areas, maximum vulnerability and lowest adaptive capacity zone (Pareek and Trivedi, 2011). Rajasthan has a wide range of climate varying from extremely arid to humid. The humid zone spans the southeast and east region of the study area (Hussain, 2015).

Khandelwal et al. (2017) examine the effect of change in elevation over LST (Land Surface Temperature) in Jaipur district, Rajasthan and concluded the strong linear relationship between LST and elevation for all the seasons. Pingale et al. (2014) observed both positive and negative trends of mean and extreme events of rainfall and temperature in the urban centers of Rajasthan State and found that the minimum and maximum temperature showed significant increasing warming trends on seasonal scale in the region. Extreme maximum and minimum temperatures over India showed increasing trend in the south and decreasing trend in the north (Jain and Kumar, 2012). Whereas, Dash and Mamgain (2011) have found significant decreasing trend in frequency of cold nights in the winter months except in the Western Himalayan region and found a significant increasing trend in warm days during summer in interior southern peninsular India by using resolution $1^{\circ} \times 1^{\circ}$ gridded data for the period of 1969–2005. Kothawale et al. (2010) studied the observed and future changes in temperature extreme over India and found increase in intensity and frequency of hot events and decrease in frequency of cold events. Goyal, 2004 studied the sensitivity of evapotranspiration to global warming for arid regions of Rajasthan (India) and found that the long-term changes in evapotranspiration demand can reflective implications for the arid region.

The present study considered outputs from two GCMs (Hadley Centre Coupled Model (HadCM3) & Geophysical Fluid Climate Model (GFCM21)) for three SRES scenarios (A1B, A2 & B1) available in Coupled Model Intercomparison Project 3 (CMIP3). Representative Concentration Pathways (RCPs) cover a wider range than the SRES scenarios used in previous assessments. But, in terms of overall forcing, RCP8.5 is broadly comparable to the SRES A2/A1FI scenario, RCP6.0 to B2, and RCP4.5 to B1 (IPCC, 2014). This study investigates the change in temperature over different regions of Rajasthan state in the next 100 years by using IPCC-AR4 (CMIP3). The objectives of this study were: (1) to analyze the future projection of temperature (daily maximum and minimum) in the arid climate of Rajasthan by LARS-WG5 based on CMIP3, (2) to analyze historically and predicted projection of temperature using climate indices. The analysis in this study focuses on three periods over the 21st century: an early-century period of 2011 to 2040, a mid-century period of 2041 to 2070 and a late-century period of 2071 to 2100 is denoted by (2025s), (2055s) and (2085s) respectively according to the IPCC-AR4 (CMIP3).

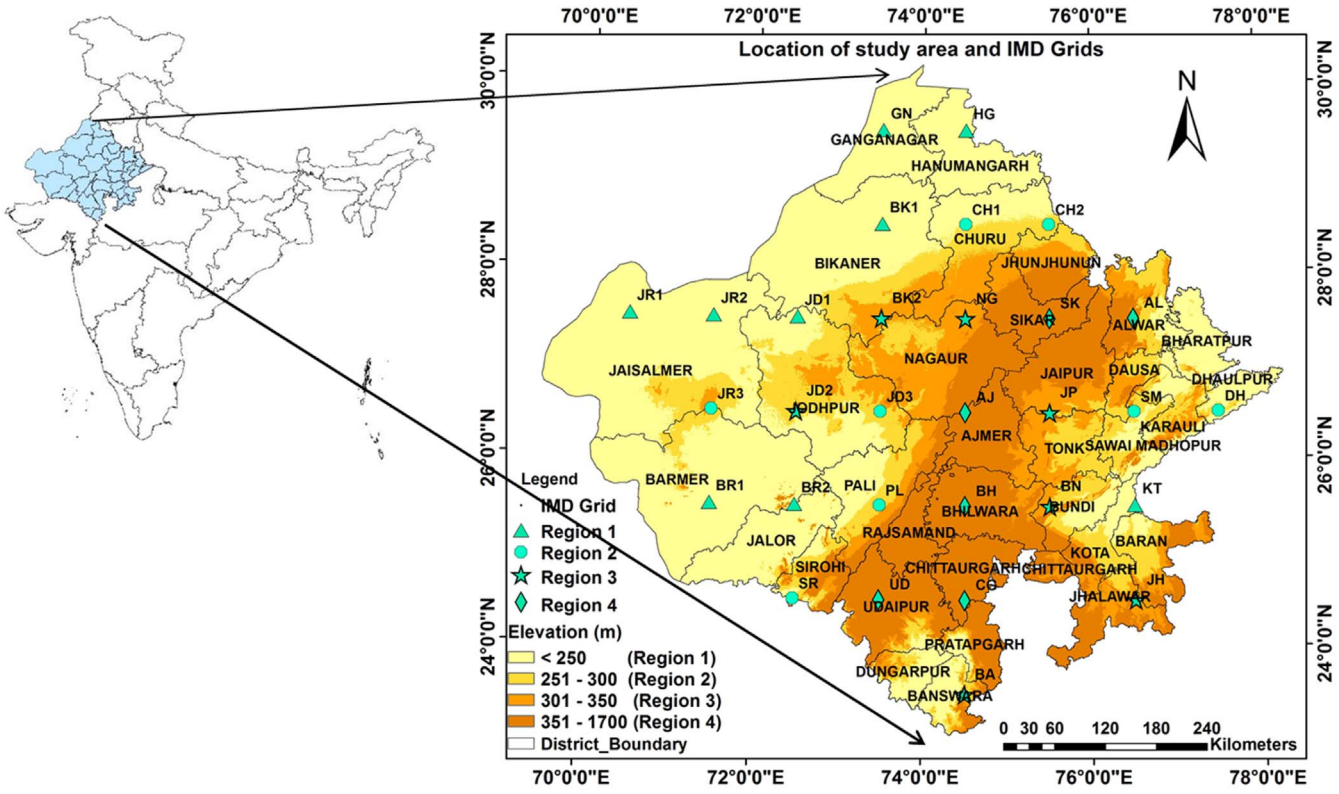


**Fig. 1.** Location map of IMD gridded points and classification of regions based on elevation (m) for Rajasthan State, India.

## 2. Study area and data used

### 2.1. Study area

Rajasthan is the largest state of India constituting 10.4% of the total geographical area. The Rajasthan state is located in the north-western region of India, with an area of 342,000 km$^2$ of which about 60% fall under the arid category (Roy, 2015). Rajasthan state is divided into 33 districts for administrative purposes and its climatic scenarios differ from arid to semi-arid. At geographical level, Rajasthan is positioned between 23°3.50′ to 30°14′ N latitude and 69°27′ to 78°19′ E longitude (Pingale et al., 2014). The climate of this region is characterized by low and erratic rainfall, extremes of diurnal and annual temperatures, low humidity and high wind velocity. The Rajasthan State is chosen for the study because of its climatic variety and elevation difference from valley floors to mountain summits (Rathore, 2004). One of oldest folded mountain chains of the world, the Aravalli is running diagonally across the state form the geomorphic and climatic boundary of the desert in the east, in the west of the Aravalli range, the rainfall is low and unpredictable distribution, extreme temperatures, low humidity and high wind velocity. The major challenge is coping with low rainfall, with a high coefficient of variation across time and space (Rathore, 2004). The Thar Desert in Rajasthan covering almost 70% of the state, which is India's largest desert located in the north-west of Rajasthan with significant influence of rainfall and temperature distribution across the state (Pingale et al., 2014).

The extreme temperature indices like, Cold Spell Duration Indicator (CSDI) in future periods decreased and Warm Spell Duration Indicator (WSDI) increased, it cause various impact may be observed on human health, increase of heat waves, and extreme weather events (Fink et al., 2004). The changes in the frequency of temperature extremes over the Rajasthan would expect in a warming future periods. If the summer days (SU25) in all the future periods increase, the mortality rate and drought condition may occur in future. For these reasons the impact of increase temperature on health and crop has been one of the most significant problems. The warm night (TN90p) and heat waves that occur early in summer may be more deadly than those that occur later in summer. The small change in cool days (TX10p) and warm days (TX90p) can lead to a large change in the estimated health effects, reduced rainfall and extreme disaster (Pascal et al., 2006). Rise in frequencies of summer days (SU25) and decline in frequencies of cool nights (TN10p) in Rajasthan will have widespread impact on various sectors such as health, power, water supply, and agriculture. In tropical nights (TR20), it is more difficult for the human body to cool down, especially for elderly or sick people (Somanathan et al., 2015). Therefore, an increase of tropical nights can lead to a rise of mortality.

During winter and summer season, the state has a huge diurnal variation in temperature. The Aravalli Mountain is playing a key role in the climatic as well as the physiographic pattern in Rajasthan. Rajasthan receives an average rainfall of 574 mm compared to the all India average of 1100 mm (Mundetia and Sharma, 2015). Western disturbances of climate cross mostly western, northern and eastern Rajasthan during the winter season, cause light rainfall and increased wind speeds which result in a wind-chill effect (Singh and Kumar, 2016). During summer (March to June) (Singh et al., 2014), the temperature generally varies between 49 °C (Max) and 40 °C (Min.). The night temperatures decrease considerably, to 20 °C to 29 °C (Singh and Kumar, 2016). During winter (December to February), the temperature is 28.3 °C (Max) and 11.6 °C (Min) (Rathore et al., 2013; Kundu et al., 2015). According to Rajasthan State Pollution Control Board (RSPCB) the state lies within the area of utmost climate sensitivity. In an era of climate change, Rajasthan is likely to suffer from water shortage in future due to overall reduction in rainfall and increased evapotranspiration due to global warming (Singh et al., 2010). There are thirty grids with resolution of 1° × 1° which cover study area. Depending on the elevation, the entire study area was divided into four physiographic regions: region 1 (< 250 m), region 2 (251–300 m), region 3 (301–350 m) and the region 4 (> 350 m). The spatial patterns of the number of grids on each region with their altitudes are shown as blue-greenish colour in Fig. 1. The region 1 is a low elevation area,

which includes Jaisalmer, Barmer, Jodhpur, Bikaner, Hanumangarh and Kota district. The temperature remains low during the winter season while summers are characterized by hot and sultry weather. The soil here is sandy & loamy. The region 2 includes Churu, Sawai Madhopur, Sirohi, Pali and Bundi district. The area of this region touch submountainous and has undulated plains with scattered hills. The climate is whole dry and is very hot in summer and cold in winter. Some area of this region intruded by granites and soil is mostly sandy loam. Some center part of the Rajasthan state includes, Jaipur, Banswara, Nagaur and Jhalawar district which lie in region 3. The climate of this region is typically humid and receives rainfall of 600 mm to 700 mm. The soil is loamy fine sand to coarse sand and yellowish brown in colour. The high elevation area region 4 includes Ajmer, Alwar, Sikar, Udaipur, Chittaurgarh and Bhilwara district. Most part of this region touches the Aravalli ranges and include mineral like limestone and sand stone. The climate is dry and hot. May and June are considered the hottest months of the year when temperature reaches 45 °C (Government of Rajasthan, n.d.).

### 2.2. Data used

Various studies used observed gridded datasets from the India Meteorological Department (IMD) and climate projections from IPCC models to study the changes in surface air temperature and rainfall, extreme events and their future projections at four Indian cities and corresponding meteorological subdivisions and homogeneous zones (Tozer et al., 2012; Dash et al., 2013). IMD gridded (1° × 1°) daily datasets for, minimum and maximum temperature (°C) (Srivastava et al., 2009) are used, covering about 30 years of data (1976–2005) of Rajasthan state was collected from the Indian Meteorological Department, Pune (http://www.imdpune.gov.in/) and the daily solar radiation ($MJm^{-2}\,day^{-1}$) data from the Waterbase (http://globalweather.tamu.edu/). The daily time series datasets for the 30 grid points of Rajasthan was then extracted from this database. The location of these grid points at which the IMD datasets available are depicted in Fig. 1 and their attributes in Table 1. In Table 1, the JAISALMER 1, BARMER 2 etc. in district name column represents the grids of IMD for temperature at resolution of 1° × 1°. Many district of Rajasthan states contain two or more grids, hence these grids represents by the number JAISALMER 1, JAISALMER 2 and JAISALMER 3. It is considered that grid within the district boundary or closure to district represents that particular district.

The LARS-WG5 is a model used to simulate present and future time series of daily weather at a single site. Among fifteen GCMs which are available in IPCC-AR4, only two of them namely HadCM3 & GFCM21 GCMs were considered for this study. The selected GCMs have three scenarios (A1, A1B and B2) cover different resolutions, varying from 1.4° × 1.4° to 4° × 5° and each has different assumptions for future. The data for these GCMs for selected SRES scenarios are available through LARS-WG5. The GCMs used in the study are listed in Table 2.

## 3. Methodology used

The moving average method was used to calculate the five year of mean temperature for base period (1976–2005) (Srivastava et al., 2009) and three future periods (2011–2040, 2041–2070 and 2071–2100) over four regions (region 1, region 2, region 3 and region 4) of Rajasthan. In order to simulate the future climate, two GCMs (HadCM3 & GFCM21) and three scenarios A1B, A2, B1 were used in the present study. The output from the these two GCMs are downscaled using the LARS-WG5 to create 30 years daily time series data for the baseline (1976–2005) and three future time periods of 2011–2040 (2025s), 2041–2070 (2055s) and 2071–2100 (2085s). Then, simple arithmetic average of two GCMs and their corresponding scenarios are taken to represent projection for the three future periods. To calculate the changes in future periods, we simply subtract the observed data from the future

**Table 1**
Grid locations and four physiographic regions based on elevation (m) over study area.

| Region | District name | Station code | Latitude | Longitude | Elevation[a] |
|---|---|---|---|---|---|
| 1 | BARMER 1 | BR1 | 25.5 | 71.5 | 106 |
| | JAISALMER 1 | JR1 | 27.5 | 76.5 | 127 |
| | BARMER 2 | BR2 | 23.5 | 74.5 | 153 |
| | JAISALMER 2 | JR2 | 25.5 | 71.5 | 160 |
| | GANGANAGAR | GN | 25.5 | 72.5 | 165 |
| | HANUMANGARH | HG | 25.5 | 74.5 | 185 |
| | JODHPUR 1 | JD1 | 28.5 | 73.5 | 190 |
| | BIKANER 1 | BK1 | 27.5 | 73.5 | 208 |
| | KOTA | KT | 25.5 | 75.5 | 228 |
| 2 | CHURU 1 | CH1 | 24.5 | 74.5 | 251 |
| | SAWAIMADHOPUR | SM | 28.5 | 74.5 | 258 |
| | CHURU 2 | CH2 | 28.5 | 75.5 | 262 |
| | SIROHI | SR | 26.5 | 77.5 | 263 |
| | PALI | PL | 29.5 | 73.5 | 281 |
| | JODHPUR 3 | JD3 | 29.5 | 74.5 | 289 |
| | JAISALMER 3 | JR3 | 26.5 | 75.5 | 291 |
| | DHAULPUR | DH | 27.5 | 70.5 | 296 |
| | BUNDI | BN | 25.5 | 75.5 | 297 |
| 3 | JAIPUR | JP | 26.5 | 71.5 | 311 |
| | BIKANER 2 | BK2 | 24.5 | 76.5 | 315 |
| | BANSWARA | BA | 27.5 | 72.5 | 316 |
| | JHALAWAR | JH | 26.5 | 72.5 | 322 |
| | NAGAUR | NG | 26.5 | 73.5 | 333 |
| | JODHPUR 2 | JD2 | 25.5 | 76.5 | 335 |
| 4 | AJMER | AJ | 27.5 | 74.5 | 432 |
| | CHITTAURGARH | CG | 25.5 | 73.5 | 460 |
| | BHILWARA | BH | 26.5 | 76.5 | 461 |
| | ALWAR | AL | 27.5 | 75.5 | 475 |
| | SIKAR | SK | 24.5 | 72.5 | 488 |
| | UDAIPUR | UD | 24.5 | 73.5 | 594 |

(Region 1: < 250 m; Region 2: 251–300 m; Region 3: 301–350 m; Region 4: 351–1700 m).
[a] Elevation of grid is taken from Digital Elevation Model (SRTM).

results (future-observation) and then change maps were developed through Arc map 10.1 to visualize how GCMs projects an increase or decrease in seasonal temperature (annual, monsoon, summer & winter) and extreme temperature indices relative to observed weather data. For the continuous spatial representation of the results, the Inverse Distance Weighted (IDW) interpolation method was used using GIS platform. A positive value indicates an increase and a negative value indicates a decrease of particular conditions in future. A zero value indicates no change between future and observed parameters. The methodological framework for the present study is shown in Fig. 2.

### 3.1. LARS-WG5 (Long-Ashton Research Station Weather Generator)

In the present study, LARS-WG5 was used for downscaling of low-resolution temperature data projected from the GCMs for all the 30 grid points in the study area. LARS-WG5 was developed by Semenov and Barrow in 1997. In context to, present and future climate conditions, LARS-WG5 is work as a stochastic weather generator which can be used for the simulation of weather data at a single site (Racsko et al., 1991; Semenov et al., 1998; Semenov and Brooks, 1999).

For the calibration of LARS-WG5 model the historical daily weather data used and determine its statistical characteristics of the climate parameters such as wet and dry spell length, minimum and maximum temperature, daily precipitation and solar radiation (Agarwal et al., 2014). Missing data in the observed data set may alter the statistics, but the long-term climatic series will still be generated. The random seed generator that makes LARS-WG5 stochastic has a default value set to 541 but can be set to any number (Mehan et al., 2017). These data are in the form of daily time series data for the climate variables, i.e., precipitation, maximum and minimum temperature and solar radiation. However, in this study, only the daily temperature (minimum and maximum) is generated. The generation of weather data in LARS-WG5

**Table 2**
List of models used in the study.

| S. No. | Models | Modelling centers | Grid resolution | | Emission scenarios included in LARS-WG5 | Year of update |
|---|---|---|---|---|---|---|
| | | | Atmospheric Lat × Lon | Oceanic Lat × Lon | | |
| 1 | HadCM3 | Hadley Centre, UK | 2.5° × 3.75° | 1.25° × 1.25° | A1B,A2,B1 | 2000 |
| 2 | GFCM21 | GFDL, USA | 2.0° × 2.5° | 1.0° × 1.0° | B1,A1B,A2 | 2005 |

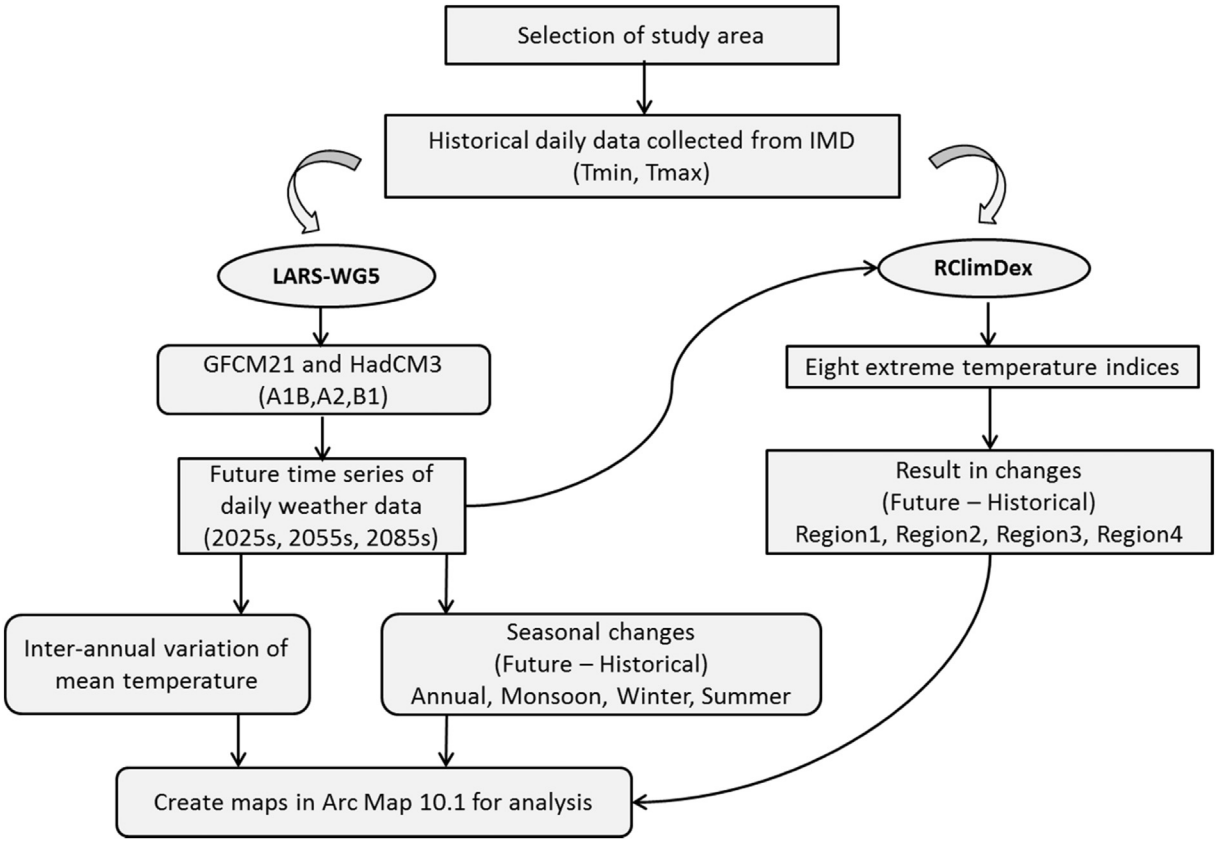
Selection of study area
Historical daily data collected from IMD (Tmin, Tmax)
LARS-WG5
RClimDex
GFCM21 and HadCM3 (A1B,A2,B1)
Eight extreme temperature indices
Future time series of daily weather data (2025s, 2055s, 2085s)
Result in changes (Future – Historical) Region1, Region2, Region3, Region4
Inter-annual variation of mean temperature
Seasonal changes (Future – Historical) Annual, Monsoon, Winter, Summer
Create maps in Arc Map 10.1 for analysis

**Fig. 2.** Methodology framework of the study.

**Table 3**
List of temperature indices (unit in days) used in the study.

| Indices ID | Indicators name | Definitions |
|---|---|---|
| CSDI | Cold spell duration indicator | Annual count of days with at least 6 consecutive days when TN < 10th percentile |
| SU25 | Summer days | Annual count when TX(daily maximum) > 25 °C |
| TN10p | Cool nights | Percentage of days when TN < 10th percentile |
| TN90p | Warm nights | Percentage of days when TN > 90th percentile |
| TR20 | Tropical nights | Annual count when TN(daily minimum) > 20 °C |
| TX10p | Cool days | Percentage of days when TX < 10th percentile |
| TX90p | Warm days | Percentage of days when TX > 90th percentile |
| WSDI | Warm spell duration indicator | Annual count of days with at least 6 consecutive days when TX > 90th percentile |

is divided into three distinct steps, namely; model calibration, model validation, and generation of synthetic weather data.

The first step is model calibration; LARS-WG5 calculates the statistical parameters for each climate variable based on the observed historical data. LARS-WG5 model calibration calculates the relevant statistical parameters for each meteorological variable from the observed historical dataset. The parameters file (*.wg) contains a statistical parameters and frequency of events for each meteorological variable derived from the observed weather data (Semenov et al., 2002). For minimum and maximum temperature, LARS-WG5 used Fourier series which can be created with parameters such as mean value and wet & dry days separately. After the observed weather data is analyzed, the derived statistical parameters are used to generate synthetic weather data representing the current climate (Etemadi et al., 2012). In the second stage of validation, the statistical parameters which were derived from the calibration process are employed to generate synthetic climate variables having the same statistical characteristics like the original observed weather data. Lastly, the statistical parameters files derived from observed weather data in the calibration process also used to generate synthetic data based on selected emission scenario

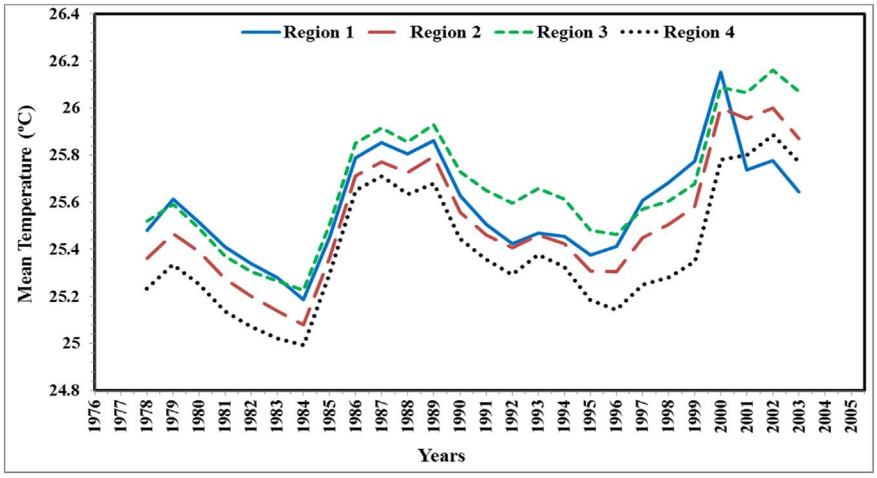


**Fig. 3.** Five years moving average of mean temperature (°C) over four regions of Rajasthan during the period 1976–2005.

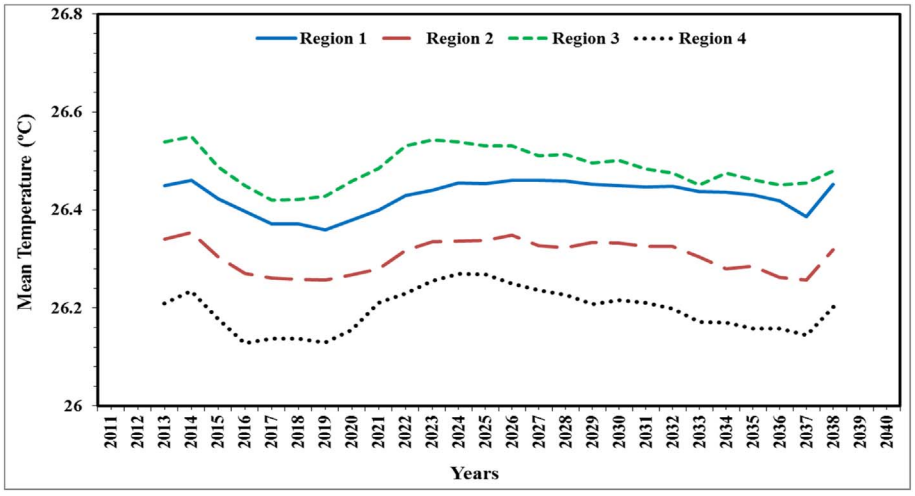


**Fig. 4.** Five years moving average of mean temperature (°C) over four regions of Rajasthan during the period 2011–2040.

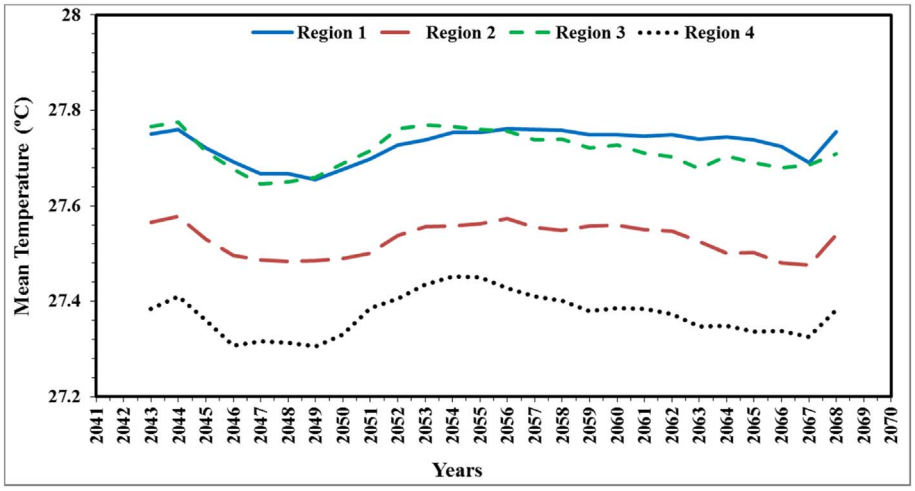


**Fig. 5.** Five years moving average of mean temperature (°C) over four regions of Rajasthan during the period 2041–2070.

simulated by GCMs (Tayebiyan et al., 2014). The more detailed procedure is given in LARS-WG5 user manual version 3.3(ref). 22. (http://www.rothamsted.ac.uk/mas-models/larswg.php).

Geographic Information System (GIS) is a versatile tool for storing, manipulating, retrieving, analysing and modelling for both spatial and non-spatial datasets (Maguire, 1991). Maps of predicted change in maximum and minimum temperature are prepared using ArcGIS 10.1 for three future periods i.e. 2025s, 2055s & 2085s.

### 3.2. Extreme temperature indices

To determine, the change in extreme temperature events during different future periods, temperature data for the baseline period and for the future periods is represented by certain indices. The indices were chosen so as to represent the variety of temperature characteristics and their extreme behaviors. There is a total of 27 indices are considered by the Expert Team on Climate Change Detection and Indices (ETCCDI)

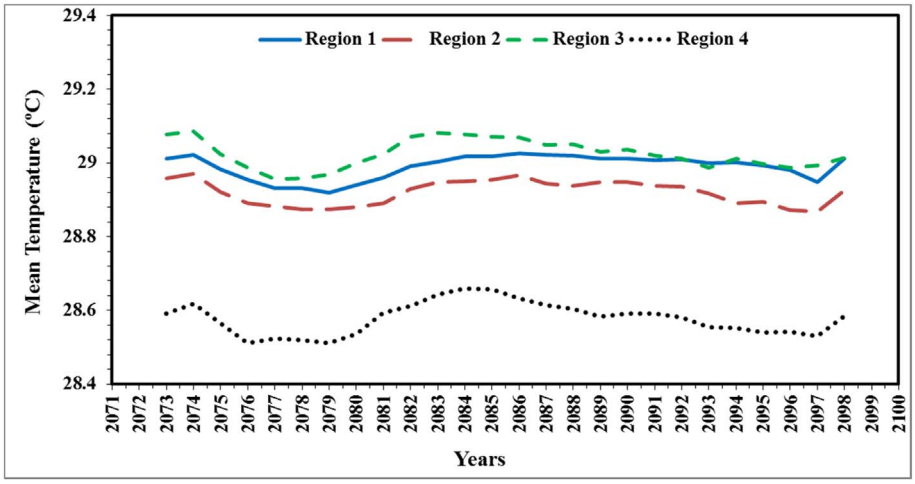


**Fig. 6.** Five years moving average of mean temperature (°C) over four regions of Rajasthan during the period 2071–2100.

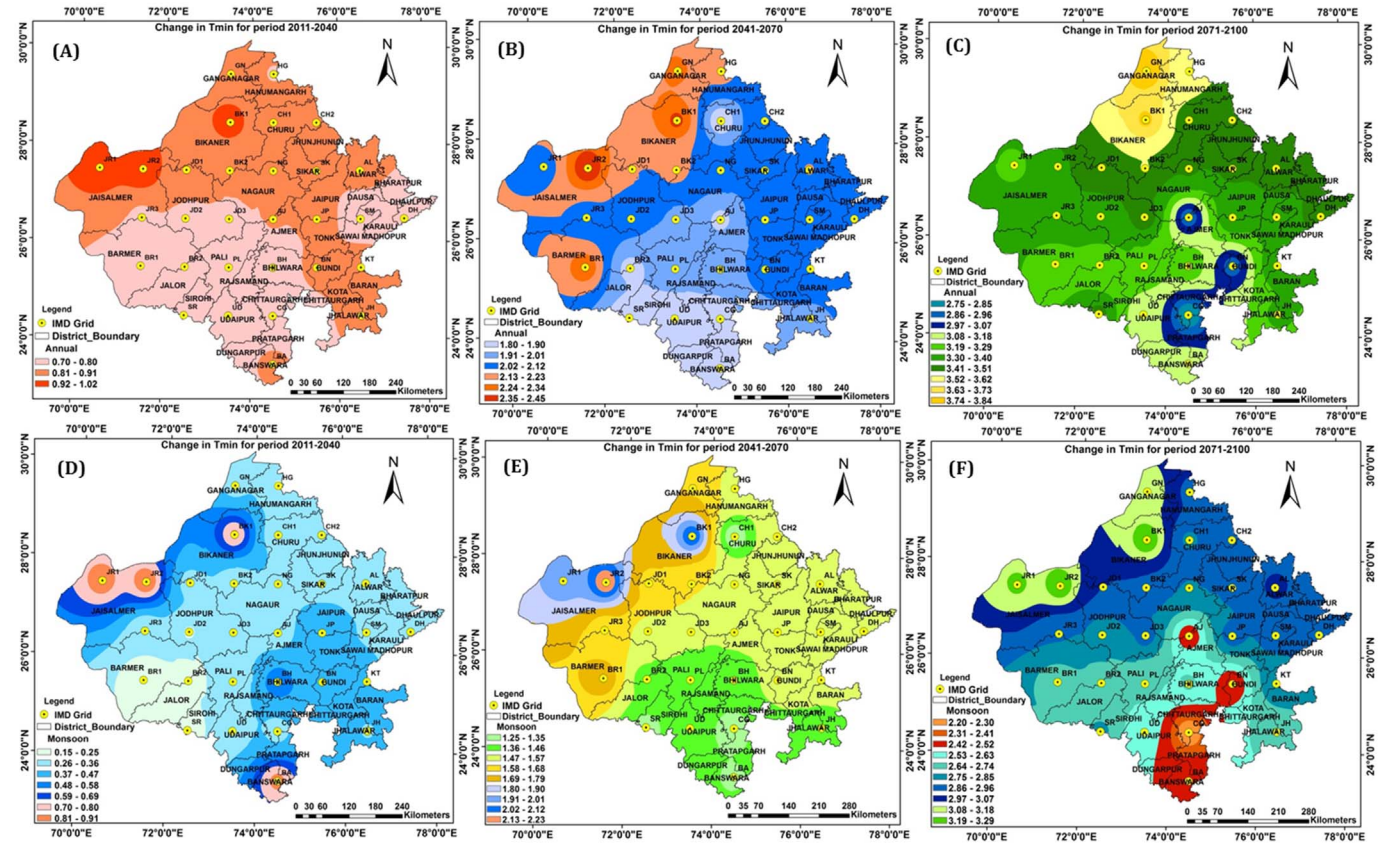
(A) Change in Tmin for period 2011-2040
(B) Change in Tmin for period 2041-2070
(C) Change in Tmin for period 2071-2100
(D) Change in Tmin for period 2011-2040
(E) Change in Tmin for period 2041-2070
(F) Change in Tmin for period 2071-2100
Legend
IMD Grid
District_Boundary
Annual
Monsoon
Kilometers

**Fig. 7.** Changes in minimum temperature (°C) over Rajasthan during the period 2011–2040 (A & D), 2041–2070 (B & E) & 2071–2100 (C & F) with respect to corresponding 1976–2005. Upper and lower panel depicts annual and monsoon months respectively.

(Peterson and Manton, 2008) and are available at (http://etccdi.pacificclimate.org/data.shtml).

These indices are based on daily temperature values and daily precipitation amounts, and some are based on fixed thresholds that are of relevance to particular applications (Wu and Huang, 2016). For the entire twentieth century as well as the past five decades, several temperature indices were computed and analyzed at both global and regional level (Alexander et al., 2006; Pal and Al-Tabbaa, 2009). However, only eight temperature indices selected for this study. Some of the extreme temperature indices are percentile based. Cool days (nights) are defined as the annual count when the maximum (minimum) temperature is less than the 10th percentile, on the other hand, warm days (nights) are annual or monthly count when the maximum (minimum) temperature is greater than the 90th percentile. The definitions of selective indices are presented in Table 3. These indices were calculated on a yearly basis for both the baseline (1976–2005) and different future periods. The indices were calculated using the RclimDex package developed by the Meteorological Service of Canada available at http://pacificclimate.org/software.shtml.

## 4. Results and discussion

In order to simulate the future climate, two GCMs were used with three SRES scenario (A1B, A2 & B1) and LARS-WG5 was simulated to create daily weather time series for the three time periods of 2025s, 2055s and 2085s. For the model validation, a synthetic weather time

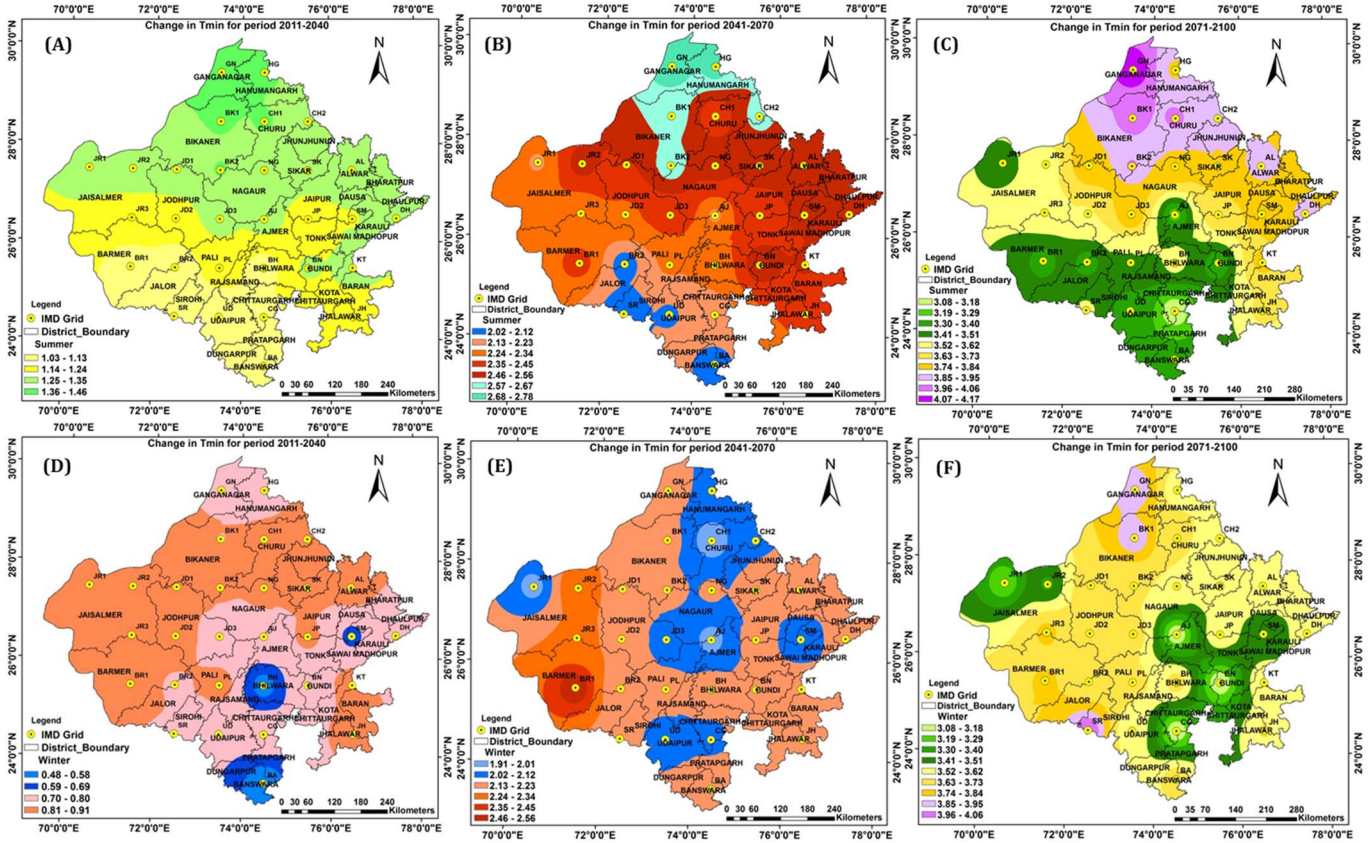


**Fig. 8.** Changes in minimum temperature (°C) over Rajasthan during the period 2011–2040 (A & D), 2041–2070 (B & E) & 2071–2100 (C & F) with respect to corresponding 1976–2005. Upper and lower panel depicts summer and winter months respectively.

series was generated using the parameter files during the model calibration step. The stochastic weather generator LARS-WG5 used the observed daily weather data to calculate a set of parameters for probability distributions of weather variables, which are used to generate synthetic weather time series of any length by randomly selecting values from the appropriate distributions in a particular location. 30-years long daily weather time series was generated for each grid point of the study area. The result of the LARS-WG5 was indicating in maps, which includes simulated seasonal change (annual, monsoon, winter and summer) for the future periods corresponding to the observational period. In addition, the maximum and minimum temperatures were also analyzed the unevenness of both the observed and generated future temperature for respective seasons by calculating the monthly average from the downscaled daily time series data.

In this study, the observations are made based on the seasonal changes for minimum and maximum temperature as mentioned above where the climatic conditions varied frequently the entire year. The time from March to June is the time of summer season in Rajasthan and June is the hottest month in Rajasthan. The month of November to February fall under winter season where January is supposed to be the coldest month of the entire season, and the time of the monsoon is from July to October.

### 4.1. Variations of mean temperature

The moving average method was used to calculate the five year of mean temperature for base period (1976–2005) and three future periods (2011–2040, 2041–2070 and 2071–2100) over four regions of Rajasthan are depicted in Figs. 3 to 6. Overall, the highest average mean temperature for all periods was observed in region 3 i.e. north-east and north-western part of Rajasthan. The average mean temperature for four regions revealed increasing trend in mean temperature during the historical 30 years (1976–2005) as shown in Fig. 3. In period 1976–2005, the average mean temperature was observed highest in region 3 i.e. 26.2 °C during 2002. Whereas the minimum mean temperature was observed in region 4 i.e. 25.0 °C in 1983 and 1984, through which increase in mean temperature about 1.2 °C as shown in Fig. 3. In this period after 1996 the mean temperature was increased constantly. The average mean temperature for 2011–2040 was highest in region 3 i.e. 26.5 °C which includes Jaipur, Nagaur, Bikaner, Banswara, Jhalawar and Jodhpur shown in Fig. 4. During this period, there is a lot of differences was observed between region 4 and region 3 in mean temperature i.e. 1.2 °C. Similarly for 2041–2070, the average mean temperature incessantly increased from preceding periods. The highest mean temperature was observed in region 3 i.e. 27.8 °C shown in Fig. 5. Lastly, the average mean temperature is more extreme in 2071–2100 from previous two periods. In this period the average mean temperature vary from 28.5 °C to 29.1 °C and highest observed in region 3 and minimum in region 4 due to high elevation and area come under semi-arid region. The mean temperature was increasing in the direction of south-east to north-east of Rajasthan which is shown in Fig. 6.

### 4.2. Projected seasonal changes for future minimum temperature (Tmin)

In this section, detailed projected analysis of the seasonal changes (annual, monsoon, winter and summer) for future minimum temperature carried out for three periods. Overall, for the period 2011–2040, it is observed that the minimum temperature (Tmin) in all the seasons has increased from south-east to north-west of Rajasthan and the range of temperature changes varies from 0.23 °C to 1.42 °C.

The Fig. 7 shows the changes in minimum temperature over Rajasthan during all the three future periods (2011–2040, 2041–2070 & 2071–2100) with respect to corresponding 1976–2005 for annual and

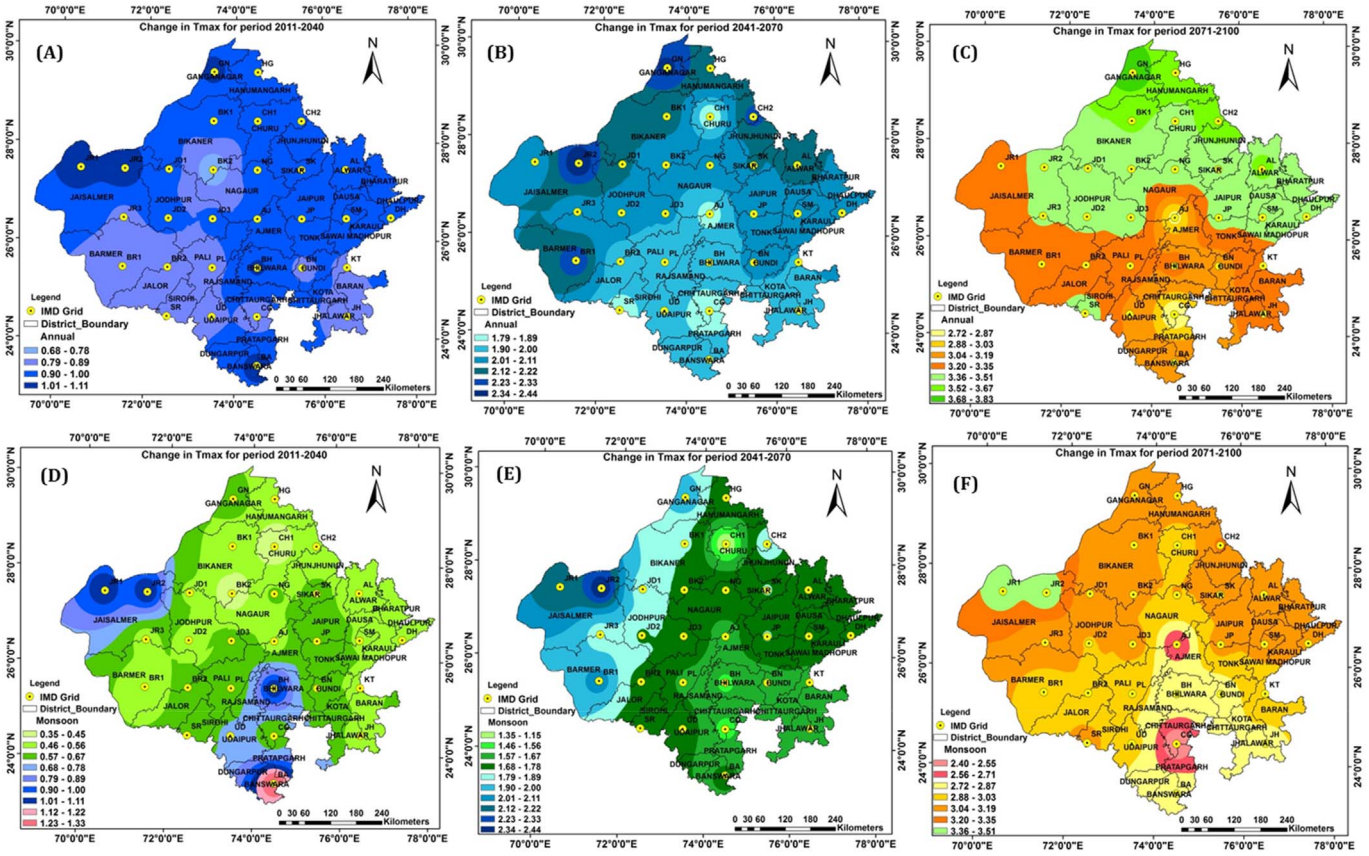


**Fig. 9.** Changes in maximum temperature (°C) over Rajasthan during the period 2011–2040 (A & D), 2041–2070 (B & E) & 2071–2100 (C & F) with respect to corresponding 1976–2005. Upper and lower panel depicts annual and monsoon months respectively.

monsoon seasons. The upper row of Fig. 7(A, B & C), represent the annual change in minimum temperature, in which the temperature increase significantly in all the three future periods with 2.75 °C to 3.84 °C in in western part of the study area. For period 2011–2040, the utmost change in the minimum temperature observed in western part of the study area i.e. Jaisalmer 2 (1.01 °C) and minimal change in south-western part of the study area i.e. Barmer 2 (0.70 °C) as shown in Fig. 7(A).

While, Fig. 7(D, E & F) lower row, shows the monsoon seasons, in which utmost change in the minimum temperature observed in northern region of Rajasthan in all the future periods. In the monsoon seasons for period 2011–2040, the minimal change in minimum temperature is observed in Barmer 1 i.e. 0.23 °C and the utmost change in the minimum temperature is observed in Jaisalmer i.e. 0.86 °C which is shown in Fig. 7 (D). These patterns are getting more pronounced in the 2041–2070, as the changes become more extreme further into the future. As per Fig. 7(B & E), it was observed that in monsoon and annual seasons, the utmost change in the minimum temperature observed in Jaisalmer 2 and minimal change in the northern part of the study area i.e. Churu 1.

Similarly, the change in temperature is more extreme in summer and winter seasons. Fig. 8 shows the changes in minimum temperature in all the three future periods (2011–2040, 2041–2070 & 2071–2100) with respect to corresponding 1976–2005 for summer and winter seasons. The Fig. 8(A, B & C) upper row, represent the change in minimum temperature in summer seasons. The utmost change in the minimum temperature observed in south-western part of the study area. In summer, the minimal change in minimum temperature is observed in Chittaurgarh i.e. 3.08 °C. The utmost change in the minimum temperature is observed in the north region of the study area i.e. in Ganganagar 1.42 °C as shown in Fig. 8(A). For period 2041–2070, the utmost change for summer seasons is observed in the northern region of Rajasthan i.e. Ganganagar (2.76 °C) and the minimal change in the southern region of Rajasthan i.e. Sirohi (2.11 °C) as shown in Fig. 8(B). In period 2071–2100, the minimal change is observed in Chittaurgarh i.e. 3.08 °C and the utmost change in northern part of the study area i.e. in Ganganagar 4.17 °C as shown in Fig. 8(C).

The lower row of Fig. 8(D, E & F) represent the change in winter seasons in all the three future periods. As in Fig. 8(D), in winter, the minimal change in minimum temperature is observed in southern region of Rajasthan i.e. in Banswara 0.54 °C and the utmost change in the minimum temperature is observed in western region i.e. in Jaisalmer 2 (0.86 °C). This season record a considerable variation in minimal and utmost temperature in Rajasthan. For period 2041–2070, the minimal change in minimum temperature is observed in the northern region of Rajasthan i.e. in Churu 1 (1.92 °C) and the utmost change in the minimum temperature is observed in western region i.e. in Barmer 1 (2.56 °C) as shown in Fig. 8(E). In winter, the minimal change in minimum temperature for 2071–2100 is observed in the south east of Rajasthan i.e. Bundi (3.14 °C) and the utmost change in the minimum temperature is observed in Sirohi 4.01 °C as shown in Fig. 8(F). In future, it is expected that the minimum temperature will be more observed in north-western part of the study area.

### 4.3. Projected seasonal changes for future maximum temperature (Tmax)

In this section, detailed projected analysis of the seasonal changes (annual, monsoon, winter and summer) for future maximum temperature carried out for three periods. Overall, for the periods, it is observed that the maximum temperature (Tmax) in all the seasons has increased from South to North region of Rajasthan and the range of temperature changes varies from 0.41 °C to 1.34 °C.

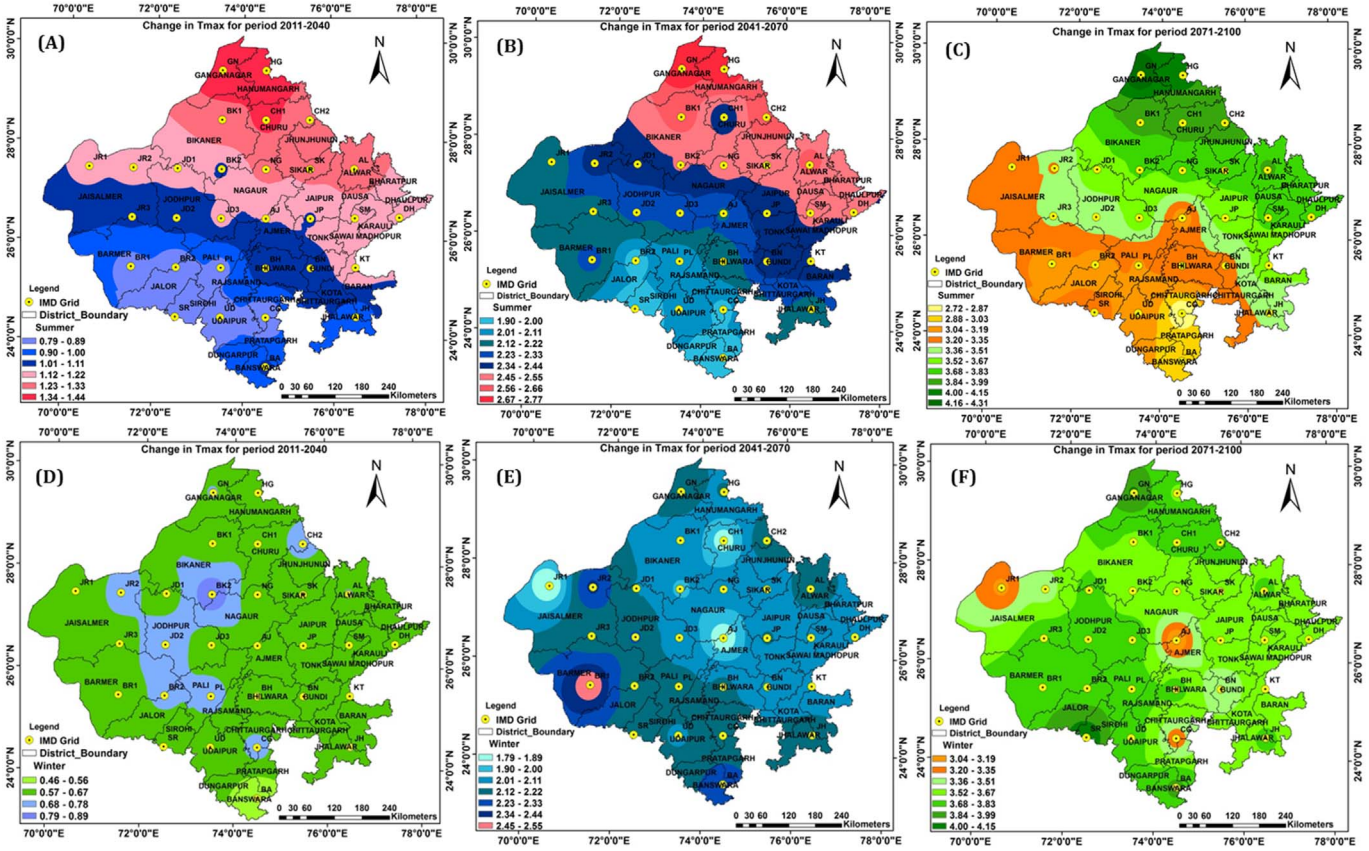


**Fig. 10.** Changes in maximum temperature (°C) over Rajasthan during the period 2011–2040 (A & D), 2041–2070 (B & E) & 2071–2100 (C & F) with respect to corresponding 1976–2005. Upper and lower panel depicts summer and winter months respectively.

**Table 4**
Changes in temperature indices and mean temperature (Tmean) over four physiographic regions of Rajasthan during the periods (2011–2040, 2041–2070 & 2071–2100) with respect to corresponding periods 1976–2005.

| Periods ⇨ | 2011–2040 | | | | 2041–2070 | | | | 2071–2100 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indices ID ⇩ | Region 1 | Region 2 | Region 3 | Region 4 | Region 1 | Region 2 | Region 3 | Region 4 | Region 1 | Region 2 | Region 3 | Region 4 |
| CSDI | − 8.4(↓) | − 8.4(↓) | − 7.7(↓) | − 8.0(↓) | − 8.4(↓) | − 8.4(↓) | − 7.7(↓) | − 8.1(↓) | − 8.4(↓) | − 8.4(↓) | − 7.7(↓) | − 8.1(↓) |
| SU25 | 12.4(↑) | 12.7(↑) | 12.4(↑) | 13.7(↑) | 28.0(↑) | 27.9(↑) | 26.4(↑) | 27.3(↑) | 38.8(↑) | 39.4(↑) | 35.5(↑) | 36.8(↑) |
| TN10p | − 0.5(↓) | − 0.6(↓) | − 0.4(↓) | − 0.6(↓) | − 0.6(↓) | − 0.6(↓) | − 0.3(↓) | − 0.6(↓) | − 0.6(↓) | − 0.6(↓) | − 0.3(↓) | − 0.6(↓) |
| TN90p | − 0.2(↓) | − 0.2(↓) | − 0.3(↓) | − 0.2(↓) | − 0.2(↓) | − 0.2(↓) | − 0.2(↓) | − 0.1(↓) | − 0.2(↓) | − 0.2(↓) | − 0.2(↓) | − 0.2(↓) |
| TR20 | 9.3(↑) | 9.1(↑) | 9.1(↑) | 8.4(↑) | 25.0(↑) | 23.8(↑) | 24.2(↑) | 23.6(↑) | 34.7(↑) | 35.1(↑) | 35.5(↑) | 33.3(↑) |
| TX10p | − 0.4(↓) | − 0.5(↓) | − 0.3(↓) | − 0.4(↓) | − 0.4(↓) | − 0.5(↓) | − 0.3(↓) | − 0.5(↓) | − 0.4(↓) | − 0.4(↓) | − 0.3(↓) | − 0.5(↓) |
| TX90p | 0.0 | − 0.1(↓) | − 0.1(↓) | − 0.2(↓) | − 0.1(↓) | − 0.1(↓) | − 0.1(↓) | − 0.2(↓) | 0.0 | 0.0 | 0.0 | − 0.2(↓) |
| WSDI | − 10.9(↓) | − 11.5(↓) | − 11.5(↓) | − 11.3(↓) | − 10.9(↓) | − 11.5(↓) | − 11.4(↓) | − 11.2(↓) | − 10.7(↓) | − 11.3(↓) | − 11.3(↓) | − 11.2(↓) |
| $T_{mean}$ | 0.86(↑) | 0.80(↑) | 0.83(↑) | 0.81(↑) | 2.15(↑) | 2.02(↑) | 2.04(↑) | 1.98(↑) | 3.41(↑) | 3.38(↑) | 3.35(↑) | 3.19(↑) |

The Fig. 9 shows the change in maximum temperature in all the three future periods (2011–2040, 2041–2070 & 2071–2100). The upper row of Fig. 9(A, B & C) represent the annual change in maximum temperature. Similarly, lower row of Fig. 9(D, E & F) represent the change in monsoon seasons in all the periods. Annually, the utmost change in the maximum temperature observed in western part of study area i.e. Jaisalmer 2 (1.03 °C) and minimal change in north-western part of the study area i.e. Bikaner 2 (0.59 °C) as shown in Fig. 9(A). During 2041–2070 period, the maximum temperature (Tmax) in all the seasons has increased from south to north region of Rajasthan and the range of temperature changes varies from 1.37 °C to 2.71 °C. As per Fig. 9(B & E), it was observed that in monsoon and annual seasons, the utmost change in the maximum temperature observed in Jaisalmer 2 and minimal change in the northern part of the study area i.e. Churu 1. The change in temperature is more extreme in 2071–2100 periods from previous two periods. Overall, the greatest change in maximum temperature is observed in this period compared to the last two periods. Similar from last period, in monsoon and annual seasons, the minimal change is observed in southern part of study area i.e. Chittaurgarh, and the temperature varies from 2.43 °C to 2.84 °C respectively as shown in Fig. 9(C & F).

The change in temperature is more extreme in summer and winter seasons. Fig. 10 shows the changes in maximum temperature in summer and winter seasons in all the three future periods (2011–2040, 2041–2070 & 2071–2100). The upper row of Fig. 10(A, B & C) represent the change in maximum temperature in summer seasons. In summer, the minimal change in maximum temperature is observed in Barmer 2 i.e. 0.84 °C and the utmost change in the maximum

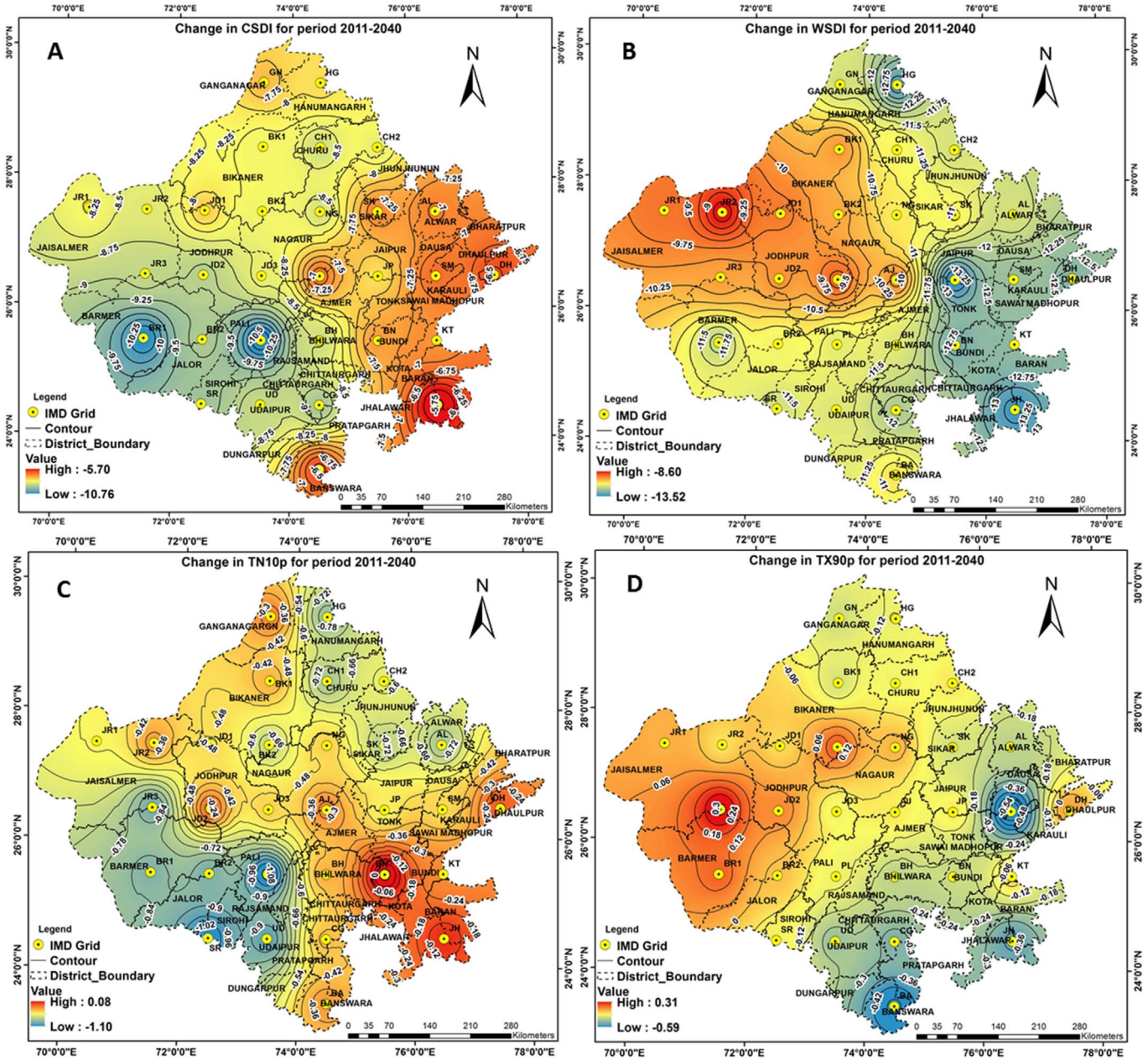


**Fig. 11.** Changes in temperature indices over Rajasthan during the period 2011–2040 with respect to corresponding 1976–2005 (A) CSDI, (B) WSDI, (C) TN10p and (D) TX90p.

temperature is observed in the northern region of the study area i.e. in Ganganagar 1.34 °C as shown in Fig. 10(A). While in 2041–2070, the utmost change in the temperature is observed in the northern region of Rajasthan i.e. Ganganagar and Hanumangarh (2.71 °C) and the minimal change in the southern region of Rajasthan i.e. Sirohi (1.91 °C) as shown in Fig. 9(B). As per Fig. 10(C), the minimal change in maximum temperature is observed in Chittaurgarh i.e. 2.83 °C and the utmost change in the maximum temperature is observed in northern part of the study area i.e., in Ganganagar 4.27 °C.

Similarly, as per Fig. 10(D, E & F) lower row shows the change in maximum temperature in winter seasons. In early period (2011–2040), he minimal change in maximum temperature is observed in southern part of Rajasthan i.e. in Banswara 0.54 °C and the utmost change in the minimum temperature is observed in north-western part of the study area i.e. in Bikaner 2 (1.11 °C), which is depict in Fig. 10(D). For 2041–2070 period, the minimal change in temperature is observed in Ajmer (1.87 °C) and the utmost change in the temperature is observed in western region i.e. in Barmer 1 (2.53 °C) as shown in Fig. 10(E). In late period (2071–2100), the minimal change in maximum temperature is observed in Ajmer (3.05 °C) and the utmost change in the maximum temperature is observed in the south west of Rajasthan i.e. Sirohi (4.01 °C) as shown in Fig. 10(F). In the end, it was observed that in future the maximum temperature will increase simultaneously for all the three future periods.

### 4.4. Change in temperature indices

To analyze the changes in the characteristics of temperature during the future periods (2011–2040, 2041–2070 and 2071–2100), eight temperature indices were selected i.e. CSDI (Cold Spells Duration Indicator), SU25 (summer days), TN10p (cool nights), TN90p (warm nights), TR20 (tropical nights), TX10p (cooler days), TX90p (warm days) and WSDI (Warm Spells Duration Indicator). Further, we have divided the study area into four physiographic regions based on elevations which are presented in Table 1 and the results of temperature indices were shown through region wise instead of station wise. The

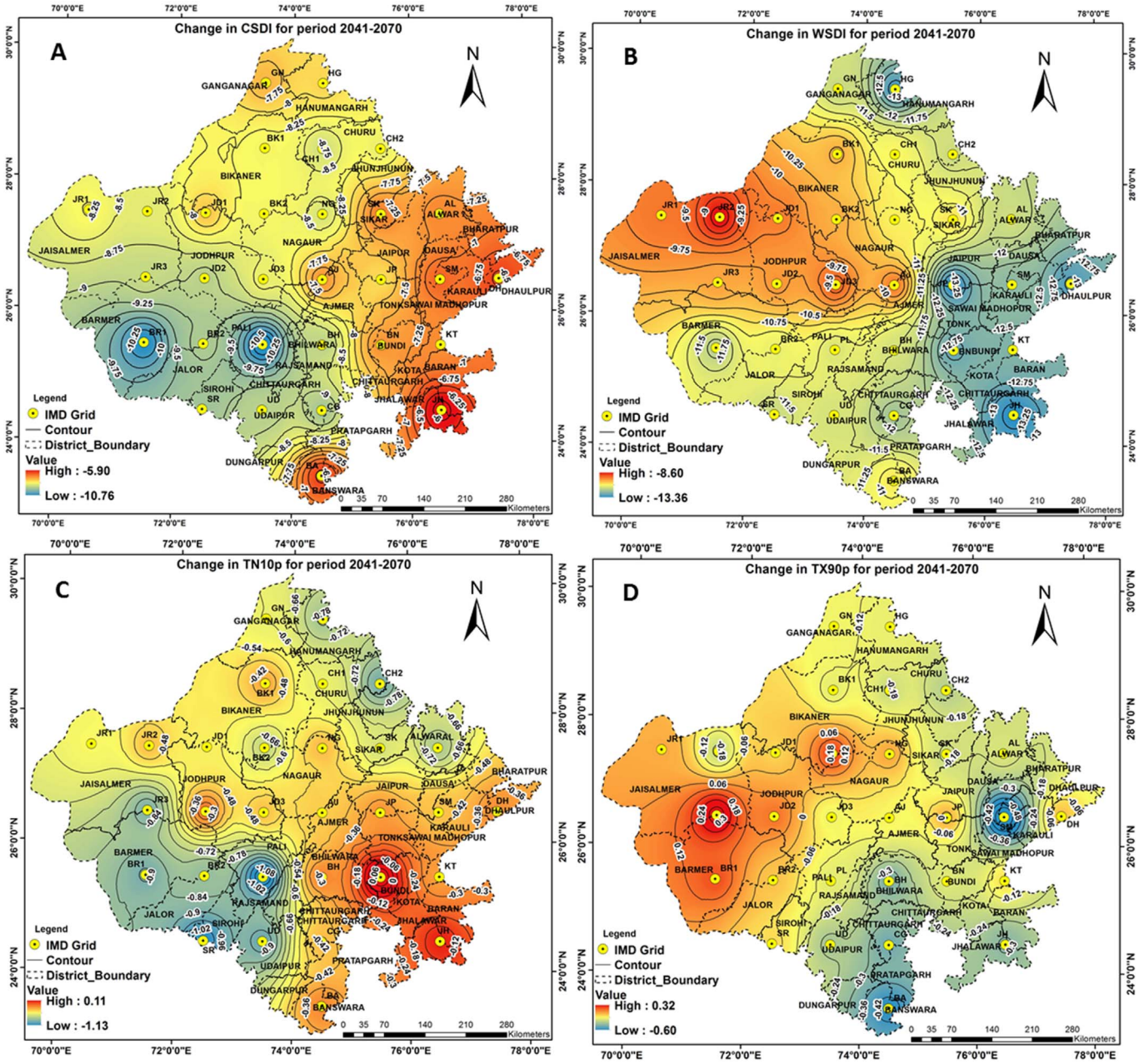


**Fig. 12.** Changes in temperature indices over Rajasthan during the period 2041–2070 with respect to corresponding 1976–2005 (A) CSDI, (B) WSDI, (C) TN10p and (D) TX90p.

selected indices and the values of the indices are presented in Table 4.

The annual occurrence of Cold Spells Duration Indicator (CSDI) significantly decreased in all the four regions and Warm Spells Duration Indicator (WSDI) increased in all the four regions for three future periods. As in Figs. (11A, 12A & 13A), the maximum decrease in Cold Spells Duration Indicator (CSDI) was projected in region 1 and region 2 followed by region 4 and region 3 for all the three future periods (2025s, 2055s & 2085s). On the other hand, the maximum increase in Warm Spells Duration Indicator (WSDI) is projected in region 1 followed by region 4. The large part of high elevation areas (region 2, region 3 and region 4) showed a significant decrease in the annual occurrence of Warm Spells Duration Indicator (WSDI), which is shown in Fig. (11B, 12B & 13B). Among the four regions, the region 1 which is characterized by low latitude areas shows the minimum change followed by region 4.

As in Fig. (11C, 12C & 13C), the percentage of cool nights (TN10p) in future periods was decreased in all the four regions. This means the number of cold events has significantly decreased in comparison with warm events. The high elevation area region 3 showed minimum increased followed by region 4. For the warm day (TX90p), the occurrence of hot day frequency is little higher than cool day (TX10p) and cool night (TN10p) frequency in all the three periods of four regions, which is shown in Fig. (11D, 12D & 13D). The maximum changed in warm day frequency was observed in region 1 followed by region 2, region 3 and region 4 for all the three future periods (2025s, 2055s & 2085s). The frequency of warm days and warm nights increases, while the frequency of cool days and cold nights decreases in all the four regions.

During all the three future periods, the occurrence of summer days (SU25) is expected to increases in all the four regions and the maximum change/increase was found in region 2 (39.4 days) and region 1 (38.8 days) during the 2071–2100 periods, followed by 2041–2070 and 2011–2040. Among all the four regions, the region1 and region 2 are characterized by low elevation areas which consist of North Western

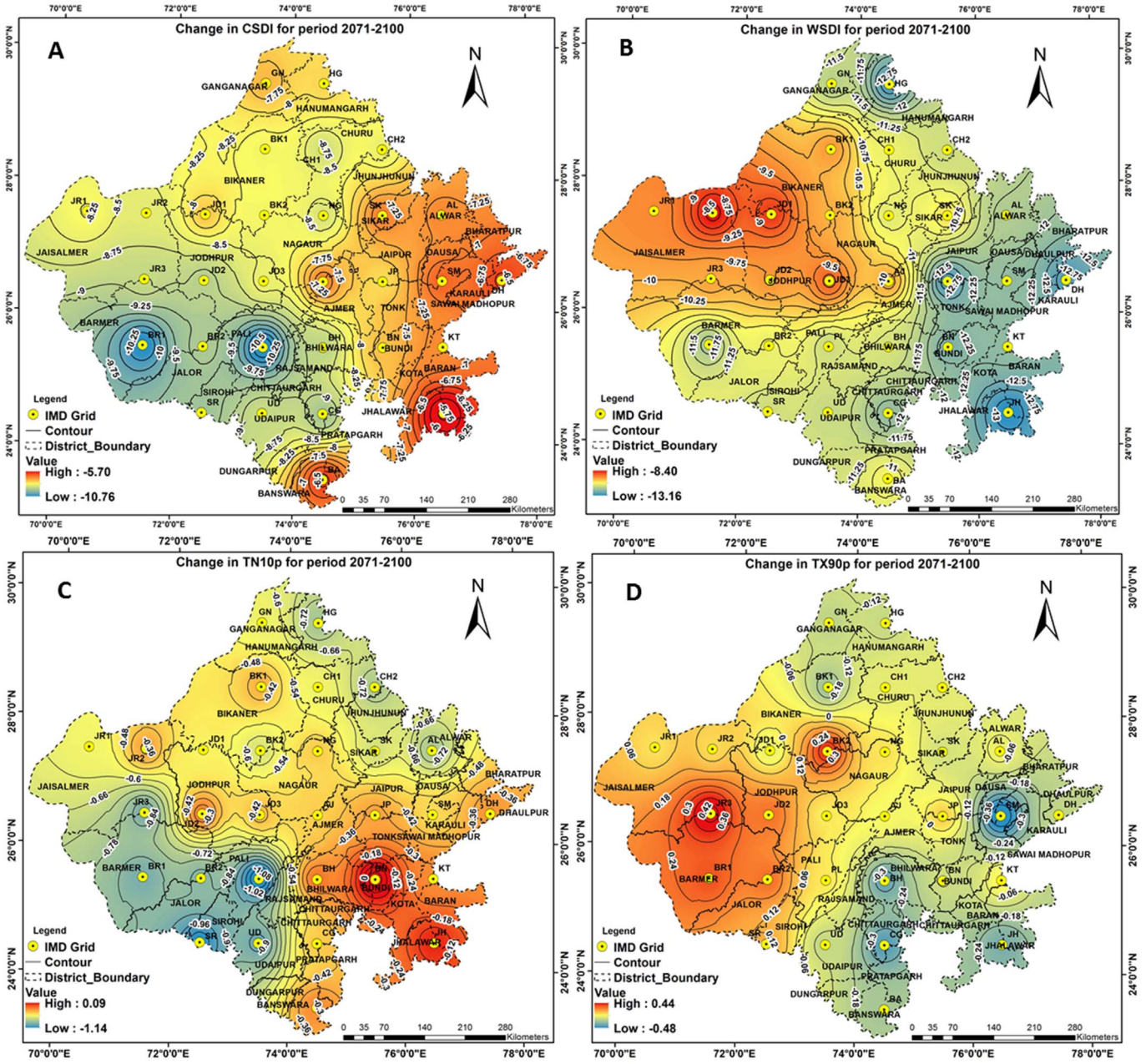


**Fig. 13.** Changes in temperature indices over Rajasthan during the period 2071–2100 with respect to corresponding 1976–2005 (A) CSDI, (B) WSDI, (C) TN10p and (D) TX90p.

regions (Jaisalmer, Bikaner, Churu, etc.) of the study area, majorly show the desert part of Rajasthan. Hence, region 1 and region 2 shows the maximum increases in the occurrence of summer days in future periods, which is presented in Table 4.

Both the percentage of cool nights (TN10p) and warm nights (TN90p) in future periods was decreased in all the four regions. The results show that the number of cold events has significantly decreased in comparison with warm events at many locations. It seems that changes are more evident in the night-time temperature than the day-time temperature. There are significant positive trends observed in the annual number of tropical nights (TR20) over all the four regions of three future periods. These increased of tropical nights were highest in last periods 2071–2100 followed by 2041–2070 and 2011–2040. During all the three periods, the percentage of cool days (TX10p) is expected to decrease in all the four regions and the maximum occurrence was found in region 2 during the 2011–2040s and 2041–2070 periods. For the warm day (TX90p), the occurrence of hot day frequency is little higher than cool day frequency (TX10p) in all the three periods of four regions. There was no change observed in region 1, region 2 and region 3 of the period 2071–2100.

The change of mean temperature ($T_{mean}$) for three periods over the regions was also analyzed. From Table 4, it can be seen that, the mean temperature ($T_{mean}$) would decreased in all the three future periods over the four regions. The utmost decreased in mean temperature observed in region 4 and the highest changed observed in region 1 for all the periods. This is because, the region 1, region 2, region 3 and region 4 characterize on the basis of elevation which is shown in Table 1. As increase in elevation, the temperature is decrease due to less air, decrease pressure and air molecule spread out. Thus, if a parcel of air from the surface rises, it undergoes an expansion, from higher to lower pressure.

## 5. Conclusions

In this study, the temperature projection is analyzed through a popular weather generator model LARS-WG5 at 30 grids of Rajasthan state with two GCMs, which gives a different sign of change in seasons (annual, monsoon, summer and winter) for all the three periods. The average mean temperature for base period and three future periods over four regions of Rajasthan was observed lowest in region 4 due to the high elevation (> 350 m) area which includes Ajmer, Chittaurgarh, Bhilwara, Alwar, Sikar and Udaipur. Whereas region 3 represents the highest mean temperature over all the periods, include of Jaipur, Nagaur, Bikaner, Banswara, Jhalawar and Jodhpur.

For a seasonal variation at all the 30 grids, the daily minimum temperature and maximum temperature for all the future periods (2025s, 2055s & 2085s) would increase from south-east to north-west region of Rajasthan. The utmost change in maximum temperature for all the three future periods (2025s, 2055s & 2085s) are observed in summer i.e. 1.34 °C, 2.71 °C and 4.27 °C respectively, compared to the baseline temperature, for whereas minimal change is predicted in monsoon i.e. 0.41 °C, 1.37 °C, and 2.43 °C respectively. For winter, the utmost maximum temperature is increased by 1.11 °C, 2.53 °C, and 4.01 °C during 2011–2040, 2041–2070 and 2071–2100 periods respectively. Mostly the increase of temperature in three periods occurred in the Western region of the study area which includes Jaisalmer, Jodhpur, Barmer, Bikaner and much more district because most of this region is covered by the Thar Desert.

The result of extreme temperature indices indicates that the number of summer days (SU25) and tropical nights (TR20) may increase in all three future periods. The annual occurrence of Cold Spells Duration Indicator (CSDI) significantly decreased and Warm Spells Duration Indicator (WSDI) increased in all the four regions for three future periods. The Aravalli range in the study area experienced minimum tropical nights during the baseline period, it may have maximum during the 2055s and 2085s. The cool nights (TN10p) and cool days (TX10p) will be expected to decreases in all the regions of three future periods of the study area, whereas the warm night (TN90p) and warm days (TX90p) are higher compared to cold events. This study examines the trends and variations in several daily and extreme temperature indices over Rajasthan state during the 21st century. It was found that the number of warm events increased significantly and the number of cold events decreased significantly during all the four regions of three periods.

The results of this study show that in future if there will be an increase in the average temperature of the study area, then global warming and droughts conditions may be occur. In general, the results showed that the increases in maximum and minimum temperatures are likely to be affecting the crop growth with increased evapotranspiration. These results may damages to both soil and water resources and creates problems such as desertification, decreases in agricultural productivity due to land degradation and soil erosion. Alterations and higher temperature may result in a spread of disease, which in turn to reduce animal productivity and possibly increase animal mortality. The higher temperature in future periods may increase heat stress for animals and hence modify livestock production. Extreme temperatures can also be harmful, when beyond the physiological limits of plants. Therefore, the crisis of the drinking water along with the scarcity of water for irrigation and other purposes is being felt very seriously. The outcomes of this study may be beneficial for development, planning, and water management.

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